ACT-167

Patent Application of

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for

Fiber Array Switch Having Micromachined Front Face With Roller Balls

RELATED APPLICATIONS

[**0005**] The present application claims the benefit of priority of copending provisional patent applications 60/197,154 filed on 4/13/2000, and 60/201,347 filed on 05/02/2000 which are hereby incorporated by reference.

FIELD OF THE INVENTION

[**0010**] The present invention relates generally to optical switches. More particularly, the present invention relates to an optical switch comprising two fiber arrays facing each other. Relative lateral translation of the fiber arrays provides switching action.

BACKGROUND OF THE INVENTION

[**0015**] Optical switches are used in optical data networks. Many varieties of optical switches have been invented, and different switches required for different applications. Switches are typically characterized by their switching speed, insertion loss, and connectivity (the number of connections that can be provided).

[**0020**] Optical computer networks will require inexpensive optical switches that are easy to manufacture and mechanically robust. Such switches may be mechanical in nature because they

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do not typically require high speed. Also, such switches should have a relatively high connectivity capability.

[**0025**] US patent no. 5,623,564 to Presby teaches an optical switch having silica waveguide chips. The chips are facing each other so that the waveguides are butt-coupled. Switching action is provided by sliding the chips transversely with respect to one another. The device can provide low insertion loss.

[**0030**] US patent no. 4,699,457 to Goodman teaches an optical fiber switch having fibers mounted on two blocks. One block can slide with respect to the other to provide switching action. The sliding motion is provided my a magnetic actuator.

[**0035**] US patent no. 5,828,800 to Henry et al. teaches a sliding mechanical optical switch. The switch has two outer waveguide arrays and a central array that is movable. Switching action is provided by moving the central array.

[**0040**] US patent no. 5,177,804 to Shimizu et al. teaches an optical switch having abutted fiber arrays which provide switching action when displaced laterally. The fiber arrays have slots for providing mechanical stops.

[**0045**] US patent no. 4,150,870 to d'Auria teaches an optical fiber switch having bundles of fibers that can move laterally to provide switching action.

[**0050**] US patent no. 5,699,463 to Yang et al. teaches an optical fiber switch having laterally translatable fiber arrays. A lens is disposed between the fiber arrays to provide relaxed alignment requirements.

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[0055] US patent no. 5,187,758 to Ueda et al. teaches an optical fiber switch having laterally translatable fiber arrays. The switch is made by cutting a single fiber array into two pieces. The fiber arrays have equal fiber spacing because they are made from the same V-groove chips.

[0060] US patent no. 5,185,825 to Shigematsu et al. teaches an optical fiber switch having laterally translatable fiber arrays. The fiber arrays have slots for alignment pins that provide mechanical stops for switch positions.

[0065] US patent no. 5,555,333 to Kato teaches an optical device for aligning an optical fiber array with optical components such as photodetectors. A photodetector chip has bumps for mechanically aligning with V-grooves in the optical fiber array.

[0070] US patent no. 5,179,609 to Blonder et al. teaches an optical subassembly or connecting optical fibers and an optical device such as a photodetector. Optical fibers are disposed in V-grooves of a V-groove chip and the V-groove chip has pits on a front face for engaging mechanical features of a submount chip. The optical fibers are oriented perpendicularly with respect to the submount chip.

[0075] US patent no. 5,778,123 to Hagan et al. teaches an optical fiber connector having alignment balls on the front surfaces of the connector. Fiber-fiber alignment is provided by mechanical contact between the connector and the alignment balls.

[0080] It would be an advance in the art of optical fiber switches to provide a mechanically robust switch with improved fiber-fiber alignment.

OBJECTS AND ADVANTAGES OF THE INVENTION

[0085] Accordingly, it is a primary object of the present invention to provide a mechanical optical fiber switch that:

[0090] 1) is mechanically tough and robust;

[0095] 2) is simple to assemble;

[0100] 3) provides low insertion loss and is capable of high connectivity; and

[0105] 4) provides good fiber-fiber mechanical alignment.;

[0110] 5) can be used with a wide variety of actuator devices.

[0115] These and other objects and advantages will be apparent upon reading the following description and accompanying drawings.

SUMMARY OF THE INVENTION

[0120] These objects and advantages are attained by an optical fiber switch having a first fiber array and a second fiber array. Each fiber array has a front face and an optical fiber terminating at the front face. Each fiber array also has a front face groove extending in a transverse direction. At least two spheres are disposed between the fiber arrays in the front face grooves so that the fiber arrays move in a transverse direction by rolling on the spheres. Transverse motion provides switching action by aligning and misaligning the optical fibers.

[**0125**] Preferably, the fiber arrays are made from anisotropically etched silicon chips. The front face grooves can be made by anisotropic etching.

[**0130**] Preferably, the spheres contact surfaces of the front face grooves, and not corners of the front face grooves.

[**0135**] Also preferably, the front face grooves and spheres are designed so that the optical fibers are spaced apart by a distance in the range of about 0.5-15 microns.

[**0140**] Also, the front faces of the fiber arrays can be angled to reduce backreflection.

[**0145**] The front face grooves can also have notches for providing passive transverse alignment.

[**0150**] The present invention includes an embodiment having a movable fiber array disposed between two stationary arrays. The movable array and stationary arrays have front face grooves and spheres are disposed in the grooves. The movable array moves in a transverse direction between the stationary arrays by rolling on the spheres.

DESCRIPTION OF THE FIGURES

[**0155**] Fig. **1** shows an exploded view of the present optical fiber switch.

[**0160**] Fig. **2** shows a side view of the present optical fiber switch.

[**0165**] Fig. **3** shows a close-up side view of a sphere disposed in two front face grooves.

[0170] Figs. **4a-4b** illustrate the operation of the present optical fiber switch.

[0175] Fig. **5** shows a side view of a preferred embodiment where the front face is angled to reduce back reflection.

[0180] Fig. **6** shows a top view of the present switch having three front face grooves.

[0185] Fig. **7** shows a side view of an embodiment where the arrays have a flat top lid.

[0190] Fig. **8** shows an embodiment having a movable array disposed between two stationary arrays.

[0195] Fig. **9** shows a perspective view of a preferred movable array having an opening.

[0200] Fig. **10** shows a preferred micromachined chip for use in making the present optical fiber arrays.

[0205] Fig. **11** shows a chip for making the present fiber arrays with a front face groove.

[0210] Figs. **12a-12e** illustrate a preferred method for making a fiber array with front face groove.

[0215] Figs. **13a-13d** illustrate a preferred method for locating an optical fiber so that a fiber endface is coplanar with the fiber array front face.

[0220] Figs. **14a-14b** illustrate a method for making the fiber arrays where the chips and optical fibers are cut in the same step.

[0225] Figs. **15a-15b** show top views of a switch having notches in the front face grooves for providing passive transverse alignment.

[0230] Figs. **16a-16e** illustrate a method for making the front face groove with an isotropic etch.

[0235] Fig. **17** shows an exploded view of a fiber array having alignment spheres for assuring alignment between top and bottom micromachined chips.

[**0240**] Fig. **18** shows a side view of an embodiment where the front face grooves and spheres are not located in the plane of the optical fibers.

[**0245**] Fig. **19** shows an alternative embodiment having GRIN lenses and ball lenses for improved optical coupling.

[**0250**] Fig. **20** shows an alternative embodiment having cylinders disposed between the fiber arrays. The fiber arrays move in a transverse direction by sliding on the cylinders.

[**0255**] Fig. **21** shows a side view of an embodiment having cylinders instead of spheres.

[**0260**] Fig. **22** shows a side view of a switch having two stationary fiber arrays and a central movable fiber array.

[**0265**] Fig. **23** shows a switch where two stationary fiber arrays are made from a shared monolithic piece of material.

[**0270**] Fig. **24** shows a switch having a shared top chip and a shared bottom chip.

[**0275**] Figs. **25-26** illustrate a preferred method for making a shared chip used in the switches of **Figs. 23** and **24**. **Fig. 25** shows the chip after anisotropic etching, and **Fig. 26** shows the chip of **Fig. 25** after cutting with a dicing saw.

DETAILED DESCRIPTION

[**0280**] The present invention provides an optical fiber switch with transversely movable fiber arrays. The fiber arrays have transverse grooves on their front faces. Spheres (e.g. ball lenses) are disposed in the grooves between the two fiber arrays. The fiber arrays move laterally by rolling on the spheres. The spheres provide for a fixed separation between the fiber arrays and for smooth sliding motion between the arrays.

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[**0285**] **Fig. 1** shows an exploded perspective view of the present optical fiber switch. The switch has two fiber arrays **20 22** with front faces **24 26**. Each fiber array has optical fibers **28** disposed in V-grooves **29**.

[**0290**] Preferably, the fiber arrays are made from V-groove chips (e.g. anisotropically etched silicon V-groove chips). The optical fibers have endfaces that are preferably polished and coplanar with the front faces **24 26**.

[**0295**] Each front face **24 26** has a front face groove **30 32**. The front face grooves **30 32** extend in a transverse direction across the front face. The transverse direction is the direction the arrays move to provide switching action; the transverse direction is indicated by the arrows **34a 34b**. The transverse direction is seen differently for the two arrays because of the exploded view. Preferably, the front face grooves in the two arrays are have the same size and shape.

[**0300**] Two spheres **36 38** are disposed in the front face grooves between the fiber arrays **20 22**. The spheres may be made of silica, alumina, glass, metal, ceramic or any other hard durable material. The spheres are preferably accurately spherical and preferably have a diameter in the range of about 100-1000 microns. Ball lenses commonly used in the microoptics industry can be used as the spheres.

[**0310**] **Fig. 2** shows a cross-sectional side view of the present optical fiber switch. The spheres **36 38** are disposed in the front face grooves **30 32**. The optical fibers **28** extend from the rear of the fiber arrays **20 22**.

[**0315**] **Fig. 3** shows a magnified side view of the sphere in the front face grooves. Preferably, the sphere contacts

surfaces (shown here as flat surfaces) of the front face grooves, and not corners **40** of the grooves. A gap distance **42** between the array front faces **24 26** is preferably in the range of about 0.5-15 microns. If the optical fiber endfaces are coplanar with the front faces, the distance between the optical fiber ends is equal to the gap distance **42**.

[**0320**] **Fig. 4a** and **4b** show top views of the present optical fiber switch illustrating the switching action. In **Fig. 4b**, fiber array **22** is displaced in the transverse direction **44**. Motion of the fiber array **22** in the transverse direction changes the connectivity of the switch, as known in the art. Motion of the fiber array can be provided by any precise linear actuator such as a piezoelectric actuator, stepper motor, solenoid or the like. Mechanisms for translating optical fiber arrays are known the art and many are applicable to the present invention.

[**0325**] The fiber arrays **20 22** move smoothly by rolling on the spheres **36 38**. Preferably, the front face grooves **30 32** have a hard, wear-resistant coating made of silicon nitride or other nitrides or carbides. The spheres can also have a hard, wear resistant coating.

[**0330**] **Fig. 5** shows a side view of a preferred embodiment where the front faces of the fiber arrays are oriented at an angle from perpendicular to the optical fiber. The optical fiber endfaces are coplanar with the front faces, so this helps to reduce backreflections.

[**0335**] **Fig. 6** shows a top view of another embodiment of the present invention where each fiber array **20 22** has three front face grooves. Three spheres are disposed in the front face grooves.

[**0340**] **Fig. 7** shows a side view of another, less preferred embodiment of the present invention where the fiber arrays each comprise a single chip with a front face groove. Each fiber array has a lid **46** that is flat and therefore does not contribute to the front face groove.

[**0345**] **Fig. 8** shows another embodiment of the present invention having two stationary fiber arrays **48**, and a single, movable array **50** disposed between the stationary arrays. The movable array rolls on spheres **36 38** disposed in front face grooves **30** and rear face grooves **53** (the front face grooves **30** and rear face grooves **53** are preferably identical). Both the movable array and stationary arrays have front face grooves **30** indicated by dotted lines. The movable array has optical fibers or other waveguides that are arranged (e.g. cross over one another) to provide different connections for different positions of the movable array. Alternatively, the 'stationary' arrays are movable and the 'movable' array is stationary (depending on the reference frame used).

[**0350**] **Fig. 9** shows a perspective view of a preferred embodiment of the movable array in the device of **Fig. 8**. The movable array has front face grooves **30** and rear face grooves **53** on a rear face **55** (not visible). The movable array has an opening **52** in the middle of the array. The opening **52** provides space for optical fibers to cross over one another. This allows the optical fibers to have different positions on each side of the movable array, which is necessary to provide switching action. V-grooves **54** are also shown, but without optical fibers. The movable array can be made of silicon and the opening can be formed by a dicing saw or chemical etching. Preferably, the V-grooves **54** and front face grooves **30** are made by anisotropic etching of silicon.

[0355] **Fig. 10** shows a perspective view of a single chip used to make the fiber arrays having front face grooves according to the present invention. The chip has V-grooves **54** for optical fibers. The chip also has V-grooves **56** for forming the front face grooves **30**. Preferably, the V-grooves **54** and V-grooves **56** are made by anisotropic etching of silicon (e.g. using KOH solution or EDP). After the V-grooves **54** **56** are formed, the chip is cut with a dicing saw along dotted line **58**.

[0360] **Fig. 11** shows a chip made according to the method illustrated in **Fig. 10**. Sloped surfaces **60** form a front face groove when two chips are mated together.

[0365] **Figs. 12a-12e** shows a side view of the preferred method for making the present fiber array chips:

[0370] **Fig. 12a**: Pattern mask on a silicon chip **61**. The mask can be made of silicon nitride, for example.

[0375] **Fig. 12b**: Expose masked chip to anisotropic wet etchant, thereby forming V-groove **56**.

[0380] **Fig. 12c**: Cut chip **61** with a dicing saw in the area of the V-groove **56**. Preferably, the cut is made along the bottom corner of the V-groove **56**.

[0385] **Fig. 12d**: Optionally, the mask is removed.

[0390] **Fig. 12e**: Two chips are assembled so that the sloped surfaces form a front face groove **30**.

[0395] **Figs. 13a-13c** illustrate a preferred method for locating an optical fiber in the array so that the fiber endface is coplanar with the front face of the array:

[0400] **Fig. 13a**: a fiducial plate **62** is pressed against the front face of the V-groove chip **61**. V-groove **54** for

the optical fiber seen from the side and is shown as a dotted line.

[0405] **Fig. 13b**: the optical fiber **28** is pressed against the fiducial plate **62** and the optical fiber is glued or bonded in place.

[0410] **Fig. 13c**: the fiducial plate **62** is removed. Preferably, the optical fiber has a polished endface.

[0415] **Fig. 13d:** After the fiducial plate is removed, a second V-groove chip **63** is placed on top of the optical fiber **28**. Preferably, the second V-groove chip is identical to the V-groove chip **61**.

[0420] Alternatively, the optical fiber is pressed against the fiducial plate AFTER the second V-groove chip is disposed on the optical fiber.

[0425] **Figs 14a-14b** illustrate a second method for making the fiber array used in the present invention:

[0430] **Fig. 14a:** The optical fiber **28** is disposed between two V-groove chips **67 69** in V-grooves (not visible). The V-groove chips have V-grooves **56** for forming the front face V-grooves **30**.

[0435] **Fig. 14b**: A dicing saw is used to cut through the chips and the optical fiber **28** in the area of the V-grooves **56**. The cut is made along dotted line **64**. The cut forms the front face V-grooves **30**.

[0440] Preferably, the dicing saw used to make the cut in **Fig. 14b** provides a relatively smooth endface for the optical fiber. If a smooth surface is not provided on the optical fiber endface, index matching liquid can be used between the fiber arrays. Optionally, the front face and optical fiber endfaces are polished after the cut is made. However, if polishing is

performed, it must not remove too much material from the front face. Removing too much material from the front face will result in a large gap spacing **42** and an increased insertion loss for the switch.

[**0445**] **Fig. 15a-15b** illustrate a preferred embodiment where the front face grooves have notches **66** for providing passive transverse alignment of the fiber arrays **20 22**. The fiber arrays are pressed together slightly so that the spheres **36** 'click' into the notches. The notches are spaced so that the optical fibers **28** are aligned when the notches are aligned. Each notch can be formed using anisotropic etching by providing a wide portion in the mask used to define the anisotropic etching. Optionally only one fiber array has notches, but it is preferable for both fiber arrays to have notches.

[**0450**] It is noted that the front face grooves can be formed by techniques other than anisotropic etching. For example, the front face grooves can also be formed by a dicing saw (preferably with a V-shaped blade) or isotropic etching. **Figs. 16a-16e** Illustrate a method for forming the front face groove with an isotropic etch:

[**0455**] **Fig. 16a:** A mask (e.g. silicon nitride) is patterned on the silicon chip.

[**0460**] **Fig. 16b:** An isotropic etch is used to form a U-shaped groove **68**.

[**0465**] **Fig. 16c:** The U-shaped groove is cut along dotted line.

[**0470**] **Fig. 16d:** Th mask is removed. The chip has a curved, sloped surface **70**.

[**0475**] **Fig. 16e:** Two chips are assembled so that the front face groove 30 is formed from the curved, sloped surfaces **70**.

[**0480**] The chip also has V-grooves for holding optical fibers which are not shown. The V-grooves can be made by anisotropic etching or a dicing saw.

[**0485**] **Fig. 17** shows an exploded view of a preferred embodiment for assembling the fiber arrays according to the present invention. Alignment spheres **72** are disposed in micromachined pits **74** between a top chip **80** and a bottom chip **82**. The pits **74** can be made by anisotropic etching, for example. The pits and alignment spheres **72** assure that top chip **80** and bottom chip **82** are aligned to one another so that sloped surfaces **60** form front face grooves. Optical fibers (not shown) are disposed in the v-grooves **54**. The alignment spheres **72** can be made of the same materials as the spheres **36**.

[**0490**] **Fig. 18** shows a side view of an alternative embodiment where the front face grooves **30 32** are located above and below the optical fibers **28**. The front face grooves **30 32** and spheres **36** provide transverse motion for the fiber arrays, but the spheres and front face grooves are not located in the plane of the optical fibers **28**. This device may require more than two stacked V-groove chips.

[**0495**] **Fig. 19** shows an alternative embodiment where the fiber arrays have GRIN lenses **90** or ball lenses **92**. The GRIN lenses **90** and ball lenses **92** collimate and focus light from the fibers so that light is collimated in the space between the fiber arrays. The GRIN lenses and ball lenses can provide improved optical coupling, as known in the art of microoptics.

[**0500**] It is noted that the spheres **36 38** disposed between the fiber arrays **20 22** do not need to have an acurate spherical shape. The spheres **36 38** can have oblate or prolate spheroid

shapes, for example. Switches with prolate or oblate spheres are understood to be within the scope of the present invention and appended claims. In case oblate or prolate spheroids are used, they should be oriented so that the fiber arrays maintain a constant spacing during translational motion (i.e. oriented so that the rotational symmetry axis is perpendicular to the plane of the fiber arrays).

[**0505**] It is also noted that the spheres **36 38** can be replaced with nonspheroidal, nonspherical objects such as cylinders. **Fig. 20**, for example, shows a top view of an embodiment where glass cylinders **96** (e.g., optical fiber sections) are used in place of the spheres **36 38**. The cylinders **96** are oriented so that an axis **98** of the cylinders extends in the transverse direction. In this embodiment, the fiber arrays move in a transverse direction by sliding on the cylinders **96**. The cylinders should be made of a material that provides smooth, low-stiction sliding. The cylinders can be made of polymers such as PTFE or polyethylene, for example. Also, the cylinders can have low-wear, low-friction coatings. **Fig. 21** shows a side view of the embodiment having cylinders **96**.

[**0510**] Also, the cylinders **96** can be replaced with cubes or other 3-dimensional solids. The present switch will operate by sliding on the object provided that the object has a suitably low sliding friction against the fiber array chips.

[**0515**] **Fig. 22** shows a side view of the switch of **Fig. 8**. The switch has two stationary fiber arrays **48** and a single movable fiber array **50**. The movable fiber array moves in a direction perpendicular to the page to provide switching action.

[**0520**] **Fig. 23** shows a side view of another embodiment where the two stationary arrays **48a 48b** share a common base chip **100.** The stationary fiber arrays have separate top V-groove chips **102 104**.

[**0525**] **Fig. 24** shows a side view of another embodiment where the two stationary arrays are made from the common base chip **100** and a common top chip **106**. The stationary arrays The stationary arrays provide a hole with the movable array **50** disposed in the hole.

[**0530**] In the present specification, the common base chip **100** and common top chip **106** are referred to generally as shared substrates. The shared substrates **100 106** can be monolithic or can be made from several bonded parts.

[**0535**] Preferably, the movable array **50** has an opening **52** so that optical fibers within the movable array can cross over one another.

[**0540**] **Figs. 25** and **26** illustrate a preferred method for making the devices of **Figs. 23** and **24**. **Fig. 25** shows an anisotropically etched silicon chip having V-grooves **110** for optical fibers, and recessed areas **112** with sloping sidewalls **114**. The sloping sidewalls provide surfaces for the spheres **36 38** to roll on. After the chip is etched as shown in **Fig. 25**, a dicing saw is used to cut out a middle portion of the chip. **Fig. 26** shows the chip after the dicing saw cut. The chip shown in **Fig. 26** can be used for the common base chip **100** or the common top chip **106**.

[**0545**] It is also noted that the fiber arrays in the present invention can have the same or different fiber pitches. If the fiber arrays have different fiber pitches, then the present

switch can provide a number of coupled 1XN switches. For example, if the arrays have pitches of 250 microns and 750 microns, then the switch will comprise 1X3 switches.

[**0550**] It is noted that the present invention is compatible with a large variety of actuating devices including piezoelectric actuators, stepper motors and magnetic actuators such as solenoids.

[**0555**] It will be clear to one skilled in the art that the above embodiment may be altered in many ways without departing from the scope of the invention. Accordingly, the scope of the invention should be determined by the following claims and their legal equivalents.